IEEE 802.22 Wireless Regional Area Networks (WRAN)

Enabling Rural Broadband Access Using Cognitive Radio Technology

Apurva N. Mody, Ph. D., (Affiliation: BAE Systems)

Chair, IEEE 802.22 Working Group

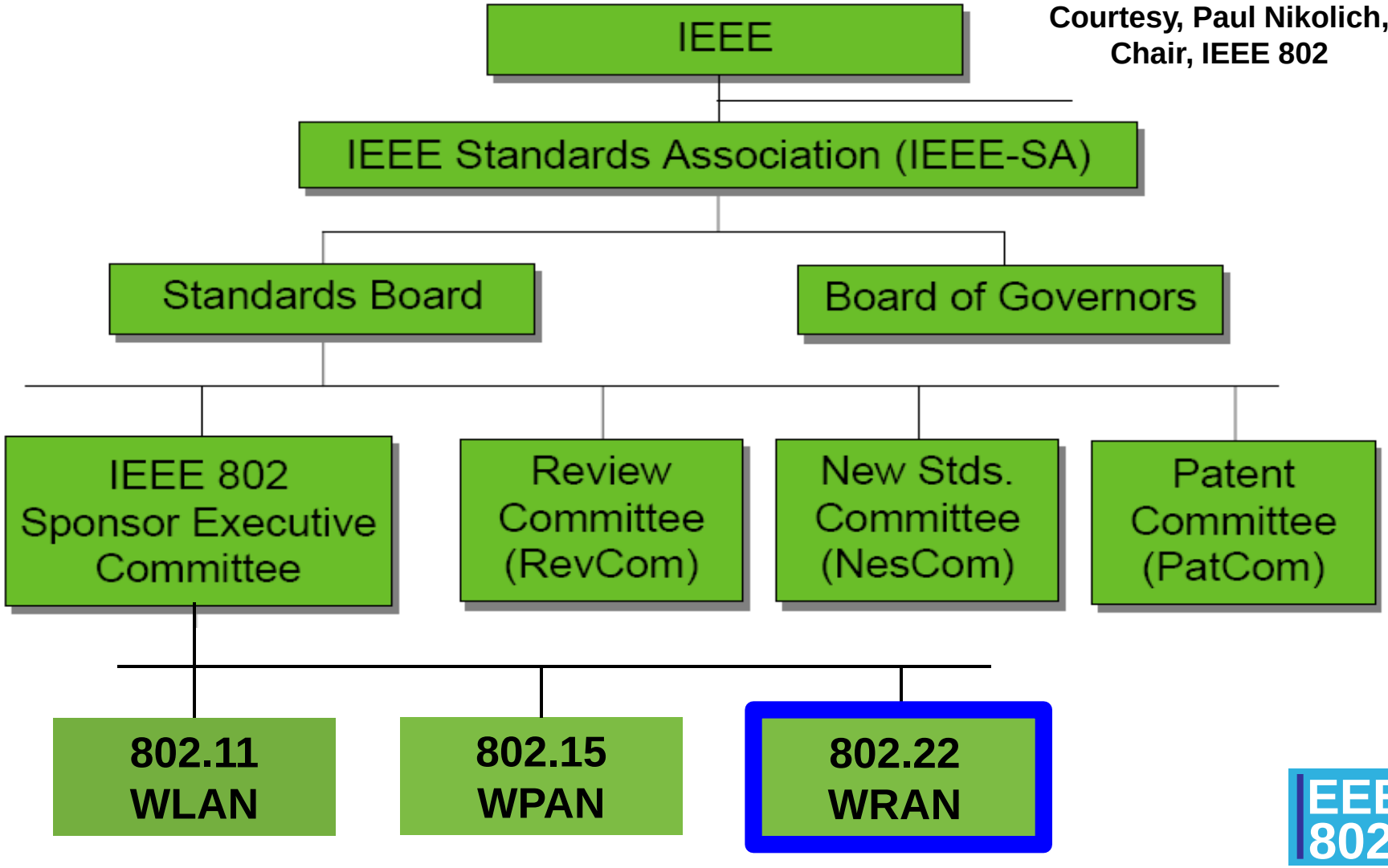
www.ieee802.org/22

apurva.mody@ieee.com,

+1-603-809-0459, +1-404-819-0314

IEEE Standards Association Hierarchy

Courtesy, Paul Nikolich, Chair, IEEE 802



IEEE 802.22 Website

IEEE 802.22 Working Group on Wireless Regional Area Networks

Enabling Rural Broadband Wireless Access Using Cognitive Radio Technology in TV Whitespaces

IEEE 802.22 Charter

The charter of IEEE 802.22, the Working Group on Wireless Regional Area Networks ("WRANs"), under the PAR approved by the IEEE-SA Standards Board is to develop a standard for a cognitive radio-based PHY/MAC/air_interface for use by license-exempt devices on a non-interfering basis in spectrum that is allocated to the TV Broadcast Service.

The approved PARs for 802.22, 802.22.1, and 802.22.2 can be viewed by clicking on their respective links.

On-going Projects

- IEEE P802.22 (Base Standard) Sponsor Ballot Draft v1.0 is available for download (Members Only)
- IEEE P802.22.2 (Standard for Recommended Practice for Installation and Deployment of 802.22 Systems) Draft v1.0 is available for download (Members Only)

Completed Projects

- IEEE 802.22.1 Standard for the Enhanced Interference Protection of the Licensed Devices was Published as an Official IEEE Standard on November 1st 2010. Download here (Members Only)

Contact Information

Working Group Chair	Apurva N. Mody, Ph. D.	BAE Systems
Working Group Vice Chair	Gerald Chouinard	Communications Research Center, Canada

www.ieee802.org/22

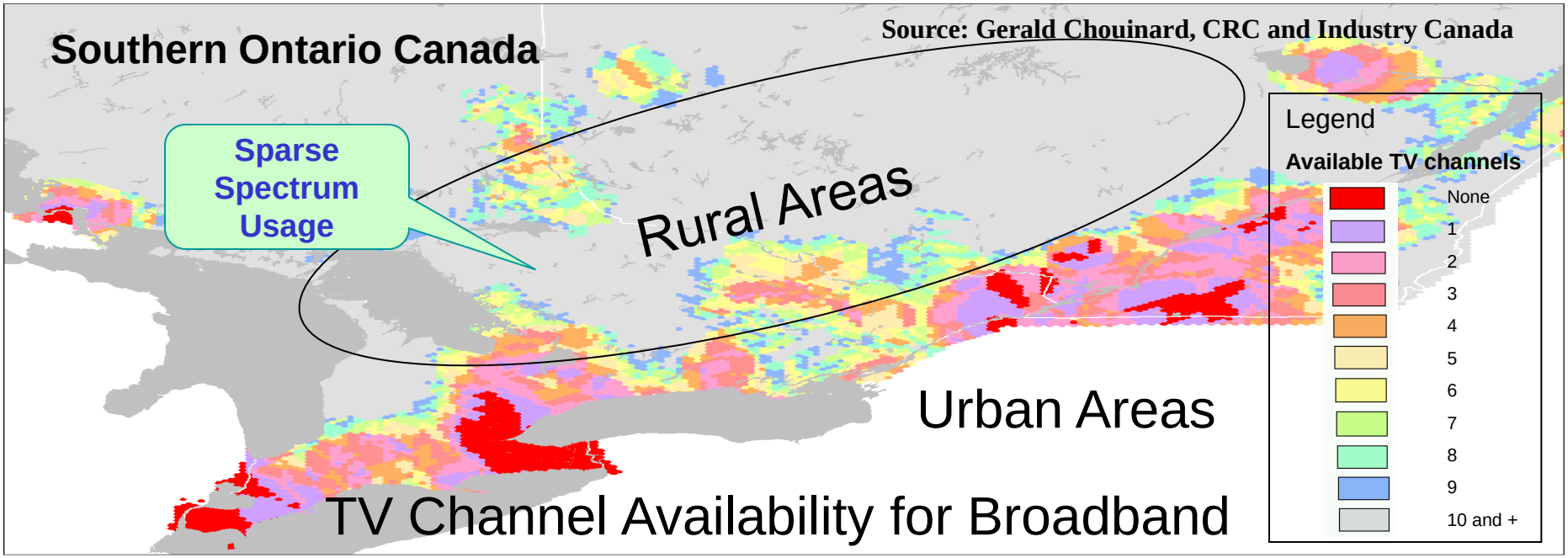
Use Cases – What does IEEE 802.22 Standard do?

- IEEE 802.22 will Provide Broadband Wireless Access to Regional, Rural and Remote Areas Under Line of Sight (LoS) and Non Line of Sight (NLoS) Conditions using Cognitive Radio Technology.
- IEEE 802.22 may also be used for other applications such as smart grid, TV (e. g. IPTV, reverse channel for on-demand), off-loading cellular telephony traffic to un-licensed spectrum, entertainment, distance learning, civic communications, rural public safety, monitoring rain forests, monitoring livestock, MDU, MTU, SoHo, Campuses, etc.

Today, more than half the population in the world resides in rural areas with hardly any access to true broadband.

IEEE 802.22 connects rural areas in emerging markets

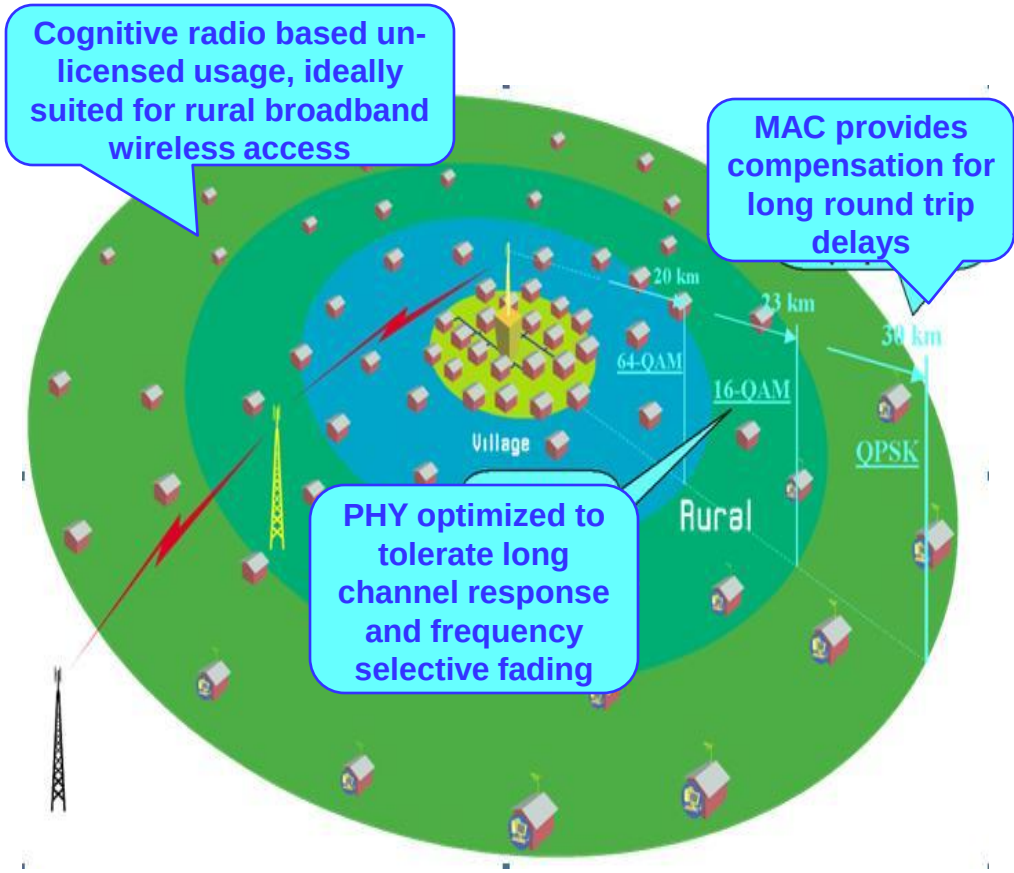
Why Now?



- Expensive to lay fiber / cable in rural and remote areas with low population density
- Traditional wireless carriers have focused on urban areas using licensed spectrum
- TV Channels in VHF / UHF bands have highly favorable propagation characteristics
- Analog TV will be transitioned to Digital TV world-wide. One analog TV channel allows up to 5 standard definition DTV signals to be transmitted.
- Excess spectrum is called the ***digital dividend*** and it can be used to provide broadband access while ensuring that no interference is caused to primary users.
- In some administrations like the United States, ***opportunistic license-exempt usage*** of the spectrum used by the incumbents is allowed on a non-interfering basis using ***cognitive radio techniques.***

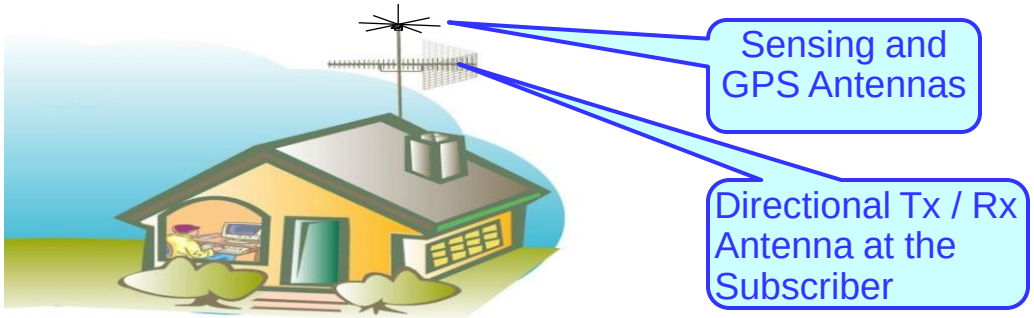
Overview of the IEEE 802.22 Standard

- Core Technology - Cognitive radio technology used to co-exist with and protect the primary users (incumbents).
- Representation – Commercial industry, Broadcasters, DoD, Regulators, and Academia
- Membership – 40 on an average (over 5 years)
- Projects – IEEE 802.22 (Likely to be completed in Summer 2011), IEEE 802.22.1 (Completed in Nov. 2010), IEEE 802.22.2 on-going.
- CONOPS - VHF and UHF band operation allows long range propagation and cell radius of 10 – 30 km, exceptionally extensible to 100 km in favorable conditions.
- PHY - Optimized for long signal propagation distances and highly frequency selective fading channels (multipath with large excess delays).
- MAC – Provides compensation for long round trip delays to provide service to up to 100 km.
- Unique features introduced for Cognitive Radio based operation: spectrum sensing, spectrum management, incumbent protection, coexistence, geo-location and security

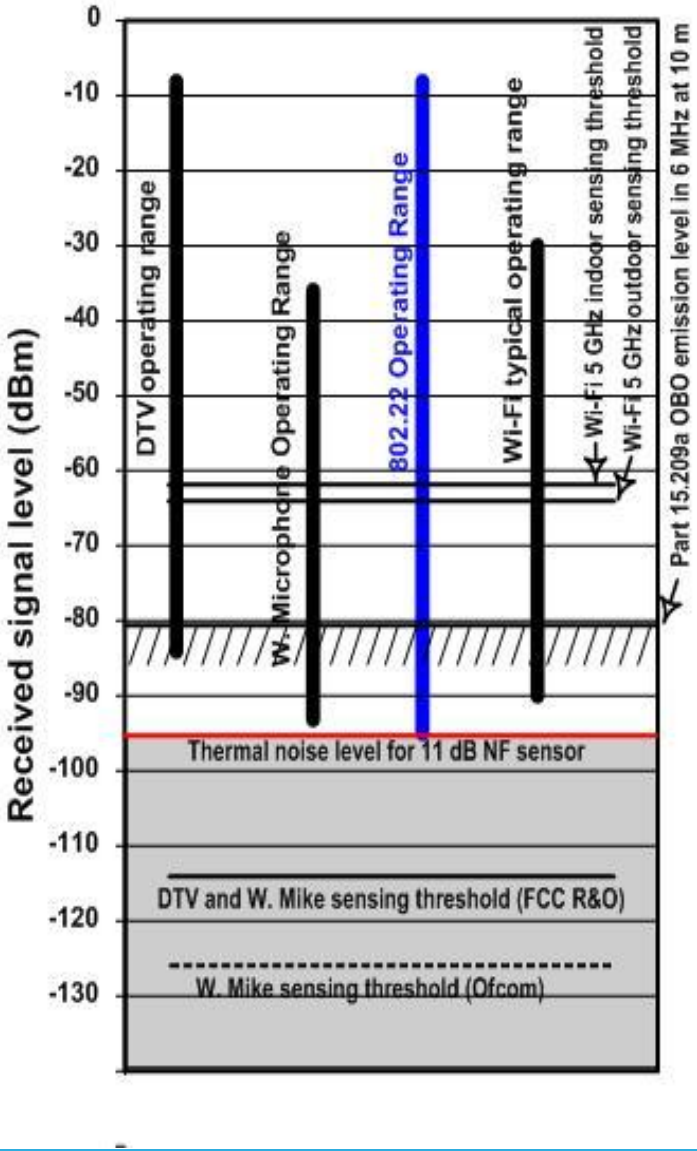


- Portability – IEEE 802.22 allows portability (nomadic use). In case the rules do change, IEEE 802.22 PHY is designed to support mobility of up to 114 km/h (no hand-off is included in the current version).

IEEE 802.22 CONOPS



- Operation in the VHF / UHF Whitespaces.
- Network Topology – Point-to-Multipoint (PMP)
- Max EIRP and Cell Radius – Fixed BS and Fixed Subscribers using 4W EIRP, Cell Radius 10 – 30 km, exceptionally extensible to 100 km under favorable conditions. 802.22 protocol has been Optimized for long signal propagation distances. (Higher power BS allowed in countries outside the USA)
- Portable Subscribers Supported.
- Tx / Rx antenna – BS uses sectorized or omni-directional antenna. At the subscriber Tx /Rx antenna is directional with 14 dB of front-to-back lobe suppression,
- Sensing antenna requires horizontal and vertical polarization sensitivities to sense TV and microphone signals, and omni-directional pattern.
- Geo-location - GPS based geo-location is mandatory, and high resolution terrestrial geo-location (triangulation) is embedded in the standard

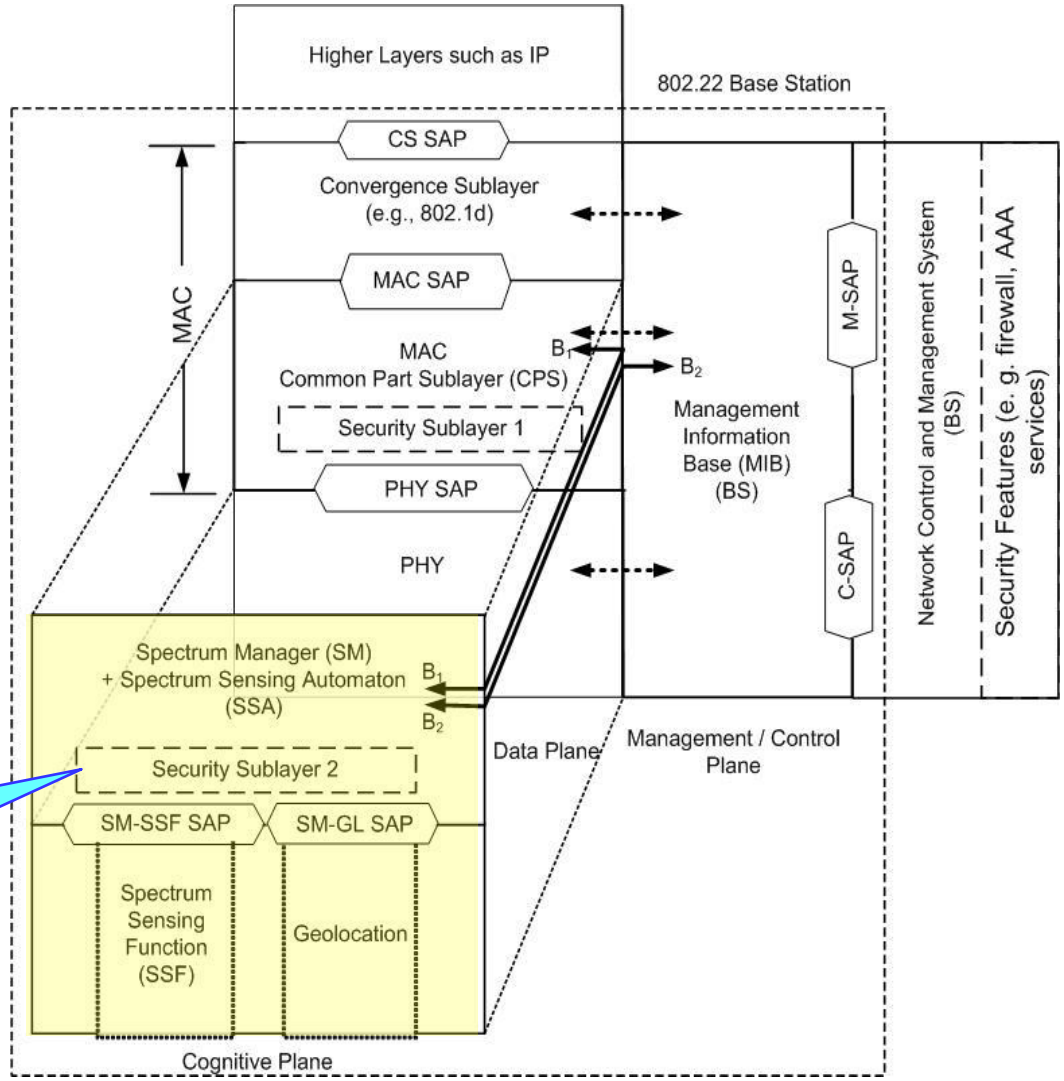


IEEE 802.22
Cognitive Node: Reference Architecture

IEEE 802.22 Provides Three Mechanisms for Incumbent Protection

- Sensing
- Database Access
- Specially Designed Beacon

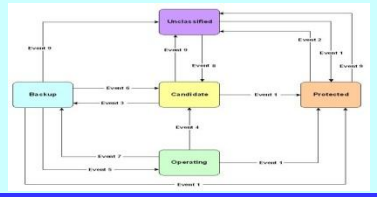
Security Sub-layers are introduced to protect non-cognitive as well as cognitive functions



Cognitive Plane is used to control the Cognitive Radio Operation. Security Sublayer 2 is introduced for protection against Cognitive Threats

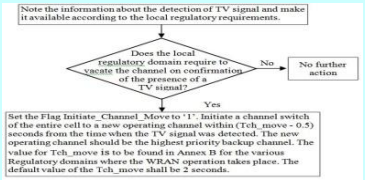
IEEE 802.22 – Cognitive Radio Capability

Channel Set Management

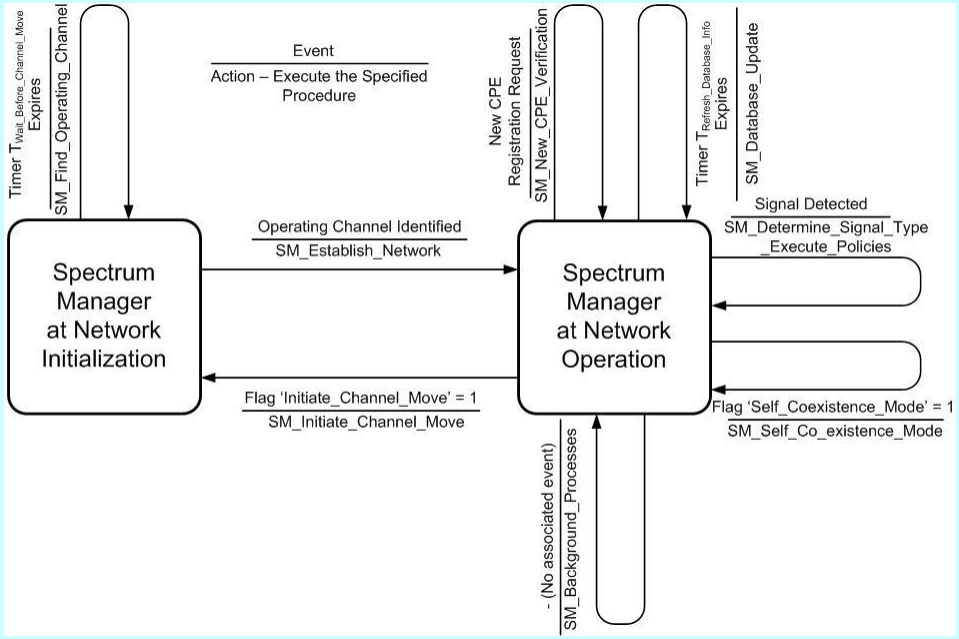


Subscriber Station Registration and Tracking

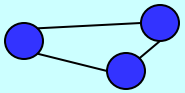
Policies



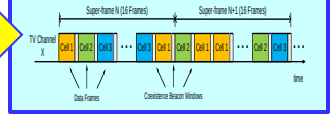
Spectrum Manager



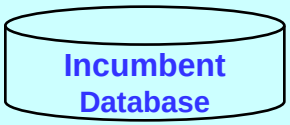
Geo-location



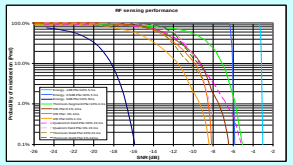
Self Co-existence



Incumbent Database Service



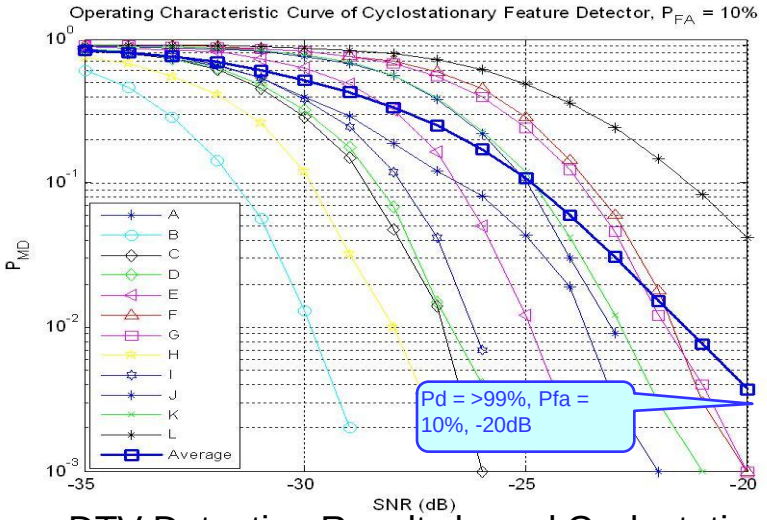
Spectrum Sensing



IEEE 802.22 – Spectrum Sensing

TV and Wireless Microphone Protection Using Spectrum Sensing

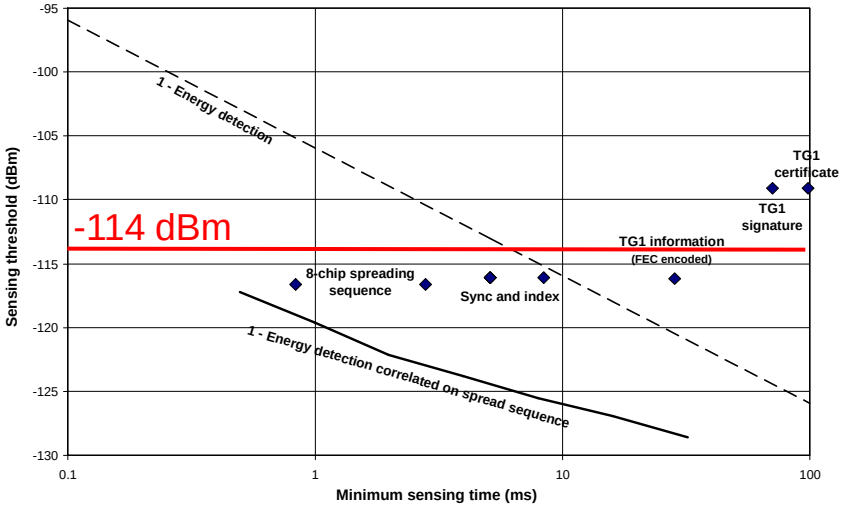
- FCC R&O requires
  - DTV protection at -114 dBm in 6 MHz of bandwidth. This amounts to an SNR of -19 dB for equivalent receiver noise figure of 11 dB and 22 dB safety margin at edge of coverage
  - Wireless microphone protection at -114 dBm in 200 kHz bandwidth. This amounts to an SNR of -3 dB for equivalent. recceiver noise figure of 11 dB.
  - Several blind and signal specific feature-based sensing schemes have been proposed and **thoroughly evaluated** using TV Broadcaster supplied over-the-air collected signals
    - ► Spectral correlation based sensing,
      Time domain cyclostationarity,
      Eigen value based sensing,
      FFT – based pilot sensing,
      Higher order statistics based sensing, etc.



DTV Detection Results based Cyclostationary Feature Detection

Wireless Microphone Protection Using Beacon

- Many studies have suggested that FCC R&O target for wireless microphones is not sufficient to protect wearable microphones (where body attenuation of as much as 27dB is possible according to the manufacturers)
- 802.22 has designed a beacon signal which will be transmitted from wireless microphone operations with up to 250 mW (as compared to 10 mW for microphones). These beacon signals consist of repeated pseudo-noise (PN) sequences and occupy a bandwidth of 78 kHz.
- Security features are provided for beacon authentication



Wireless Microphone Beacon Sensing Results

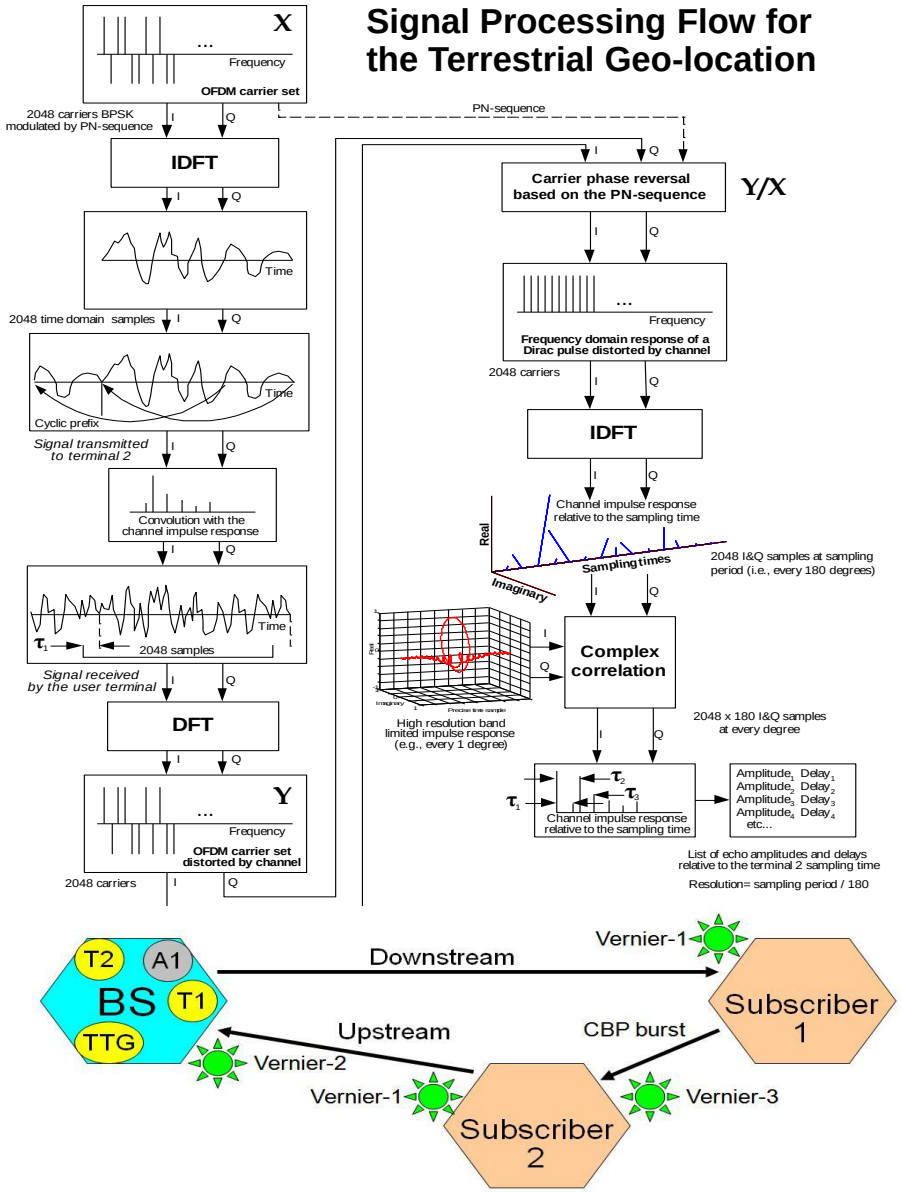
IEEE 802.22 – Geo-location

Satellite-based geo-location

- Requires GPS antenna at each terminal
- NMEA 0183 data string used to report to BS

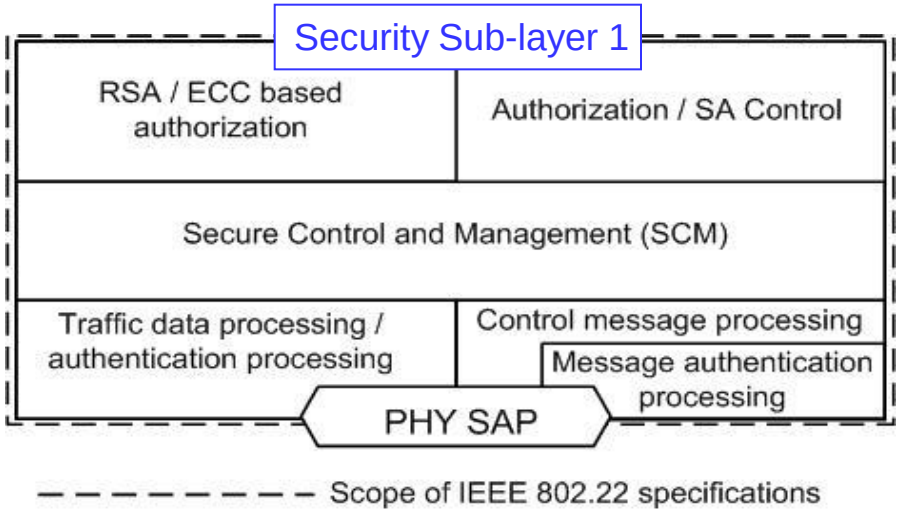
Terrestrially-based geo-location:

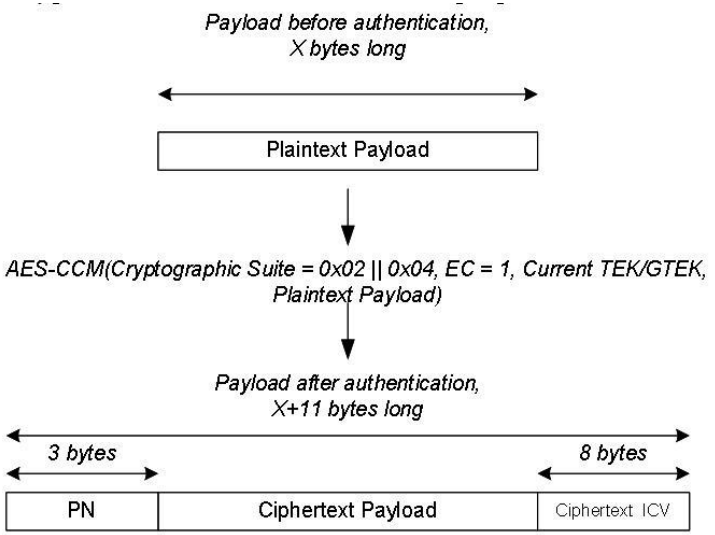
- A new scheme has been included in the 802.22 Standard requiring no additional hardware and using the characteristics and capabilities of the 802.22 standard.
- Normal BS-CPE ranging process: provides coarse ranging to an accuracy of 147.8 ns (44.3 m)
- Extended ranging process: augments the accuracy of the ranging process to 1 ns (0.3 m) by a more accurate scheme using the complex channel impulse response
- Off-line geo-location calculation: All the information acquired at the CPEs is transmitted to the BS which can delegate the calculation of the CPE geo-location to a server. Calculation is based on usual triangulation using some CPEs as waypoints.



IEEE 802.22 – Security Sub-layer 1 (Non-Cognitive)

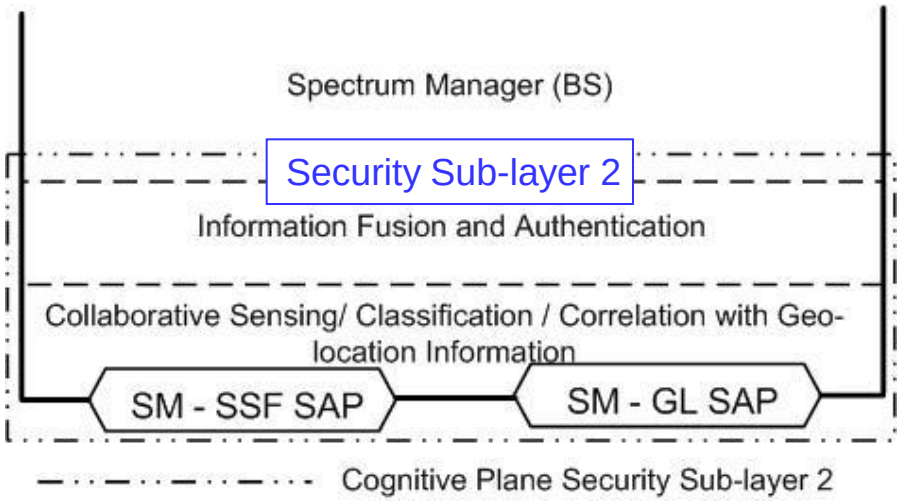
- Confidentiality and Privacy – AES (128) GCM is used for encryption and authentication
- Network Authorization – RSA and ECC based X.509 certificates are used for mutual authentication / network entry authorization.
- Integrity – AES-GCM is used to compute Integrity Check Vector (ICV). PN sequence numbers are appended to each packet.
- Authentication – Signals such as wireless microphone beacon and CBP are authenticated using ECC based digital signatures. No encryption is provided for these packets.
- Key Management – Secure Control and Management Protocol is used for key management.
- Management Messages – All management messages except for the broadcast, initial ranging and basic CID are protected.
- Device Security – Trusted Computing Group, Trusted Platform Module specifications are recommended to enable tamper-proof capability for hardware and software.

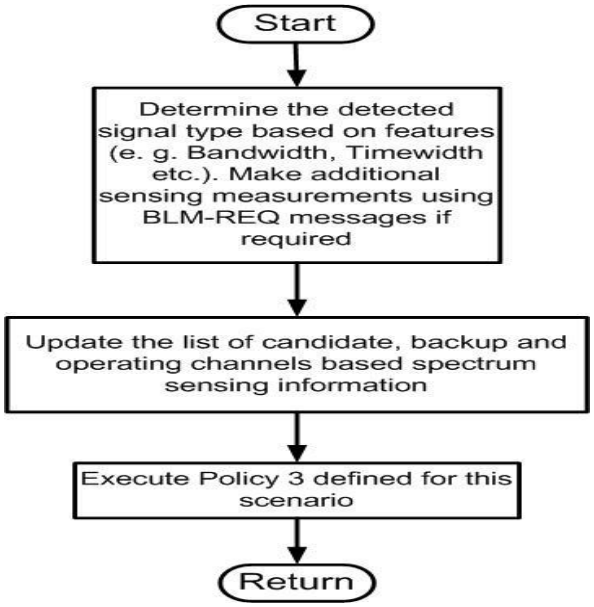




IEEE 802.22 – Security Sub-layer 2 (Cognitive)

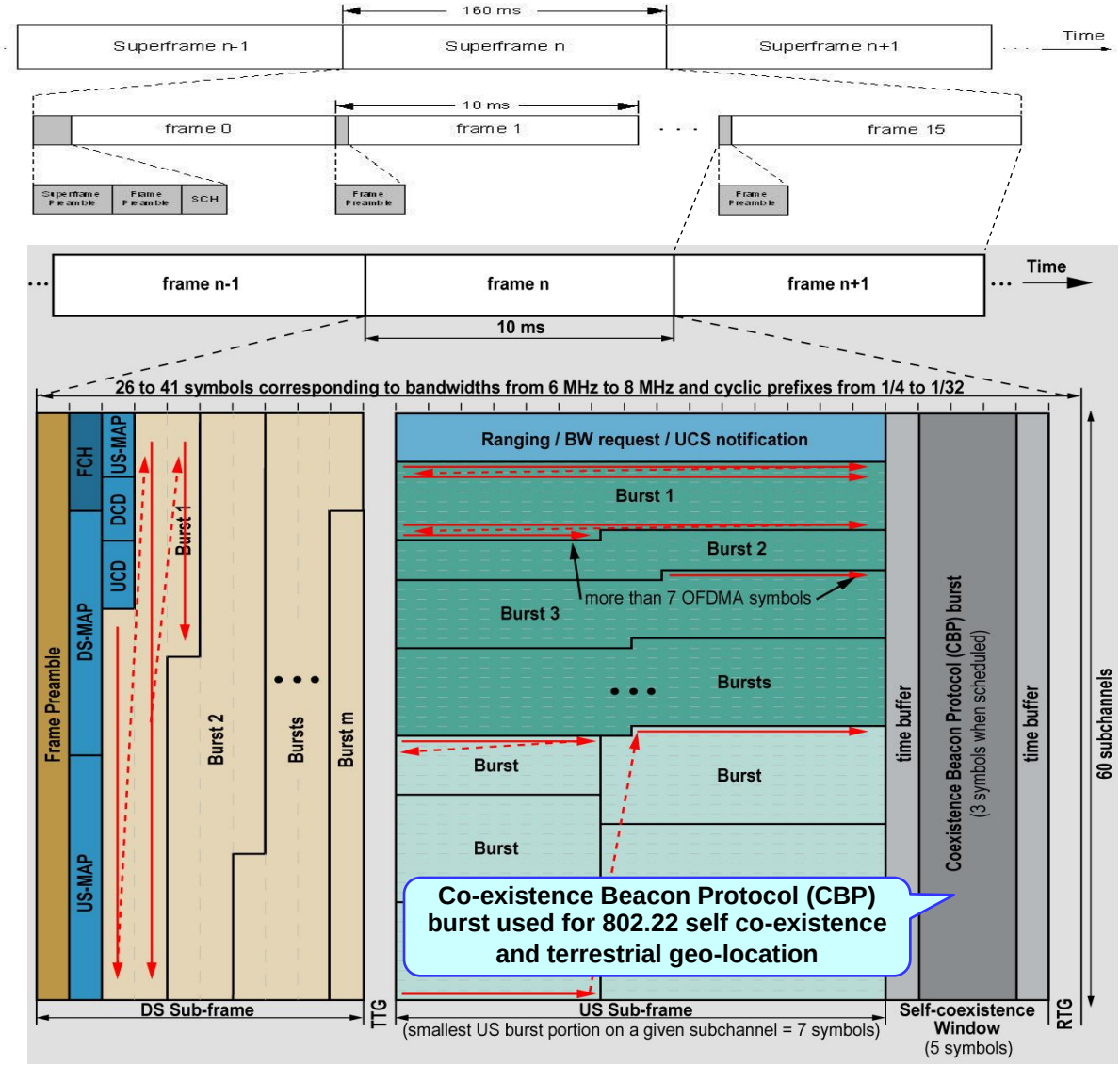
- **Spectrum Availability -**
  - Spectrum Sensing used to ensure spectrum availability for primary users.
  - Various types of signal specific and feature based sensing algorithms have been included into the standard
  - Standard recommends sensing algorithms to determine the signal type (Signal Classification)
  - Collaborative Sensing - The group in general thinks that collaborative sensing will be useful. FCC R&O requires 'OR' rule based collaborative sensing.
  - Correlation with Geo-location Information – Closely tied to collaborative sensing. It tries to cross check the spectral footprint of the detected signal based on location of the sensor
- **Spectrum Access Authorization –**
  - BS is capable of de-authorizing a subscriber at any time. Sensing and incumbent database service used for spectrum access authorization
  - Capability Check – The Spectrum Manager (SM) is capable of prohibiting a subscriber from registering if it does not have adequate sensing capabilities.
- **Radio Behavior Control**
  - IEEE 802.22 is policy driven. Policies are rule-based.



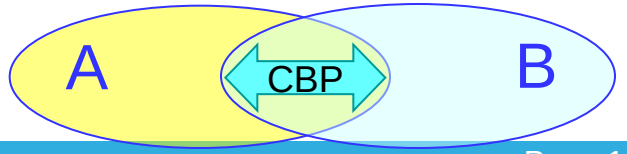


Signal classification and policy based behavior control of the 802.22 devices

IEEE 802.22 – Frame Structure



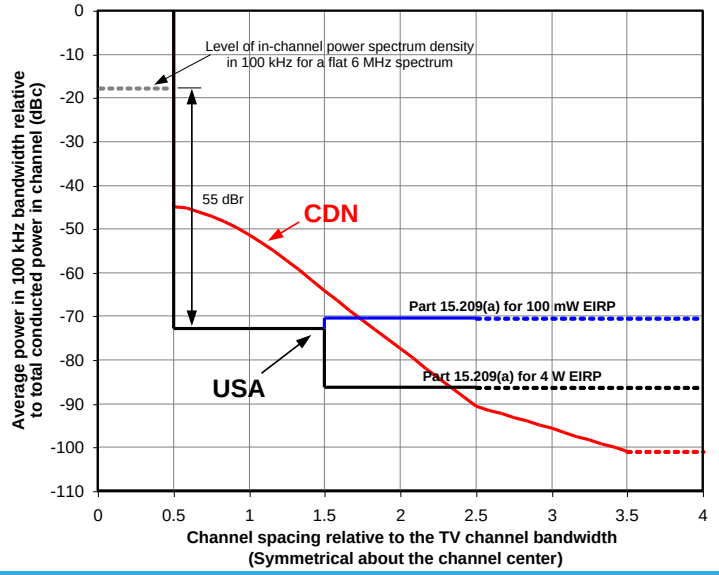
- 802.22 supports Time Division Duplex (TDD) frame structure
  - Super-frame: 160 ms, Frame: 10 ms
  - Each frame consists of downstream (DS) sub-frame, upstream (US) sub-frame, and the Co-existence Beacon Protocol (CBP) burst
  - Lengths of DS and US sub-frames can be adjusted.
- Self-coexistence Window (SCW): BS commands subscribers to send out CBPs for 802.22
  - Self- coexistence – CBP bursts contain information about the backup channel sets, sensing times, SCW scheduling, contention information
  - terrestrial geo-location and
  - whitespace device identification as required by the regulatory domain rules.



IEEE 802.22 – PHY Features

- PHY Transport - 802.22 uses Orthogonal Frequency Division Multiplexing (OFDM) as transport mechanism. Orthogonal Frequency Division Multiple Access (OFDMA) is used in the US
- Modulation - QPSK, 16-QAM and 64-QAM supported
- Coding – Convolutional Code is mandatory. Either Turbo, LDPC or Shortened Block Turbo Code can be used for advanced coding.
- Pilot Pattern - Each OFDM / OFDMA symbol is divided into sub-channels of 28 subcarriers of which 4 are pilots. Pilot carriers are inserted once every 7 sub-carriers. Pilots cycle through all 7 sub-carriers over 7 symbol duration. No frequency domain interpolation is required because of low Doppler spread in TV bands.
- Net Spectral Efficiency - 0.624 bits/s/Hz – 3.12 bits/s/Hz
- Spectral Mask - 802.22 has adopted the Spectral Mask requirements proposed by FCC for the USA. (IEEE 802.22 PHY flexible to meet Spectral Mask requirements in various countries).

TV channel bandwidth (MHz)	6	7	8
Total number of subcarriers, N_{FFT}	2048		
Number of guard subcarriers, N_G (L, DC, R)	368 (184, 1, 183)		
Number of used subcarriers, $N_T = N_D + N_P$	1680		
Number of data subcarriers, N_D	1440		
Number of pilot subcarriers, N_P	240		
Signal bandwidth (MHz)	5.6240625	6.5625	7.494375



Data Rates in NLOS Conditions

PHY capacity		Mbit/s	bit/(s*Hz)
Mod.	Rate	CP= 1/8	
QPSK	1/2	3.74	0.624
	2/3	4.99	0.832
	3/4	5.62	0.936
	5/6	6.24	1.04
16QAM	1/2	7.49	1.248
	2/3	9.98	1.664
	3/4	11.23	1.872
	5/6	12.48	2.08
64QAM	1/2	11.23	1.872
	2/3	14.98	2.496
	3/4	16.85	2.808
	5/6	18.72	3.12

PHY performance: SNR (dB)

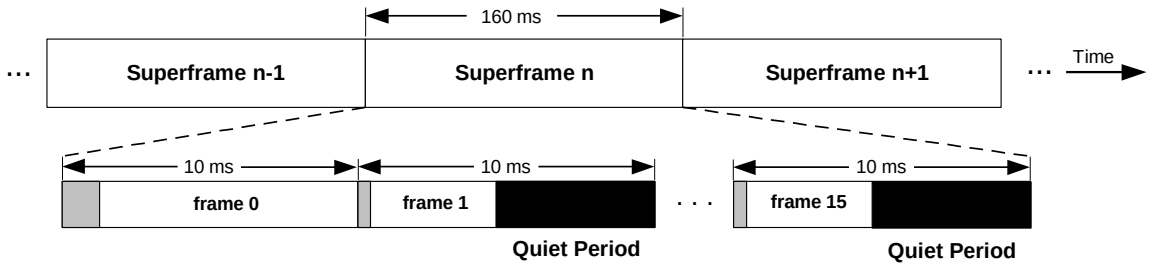
Mod.	Rate	SNR
QPSK	1/2	4.3
	2/3	6.1
	3/4	7.1
	5/6	8.1
16QAM	1/2	10.2
	2/3	12.4
	3/4	13.5
	5/6	14.8
64QAM	1/2	15.6
	2/3	18.3
	3/4	19.7
	5/6	20.9

Note: includes phase noise: -80dBc/Hz at 1 kHz and 10 kHz and -105 dBc/Hz at 100 kHz

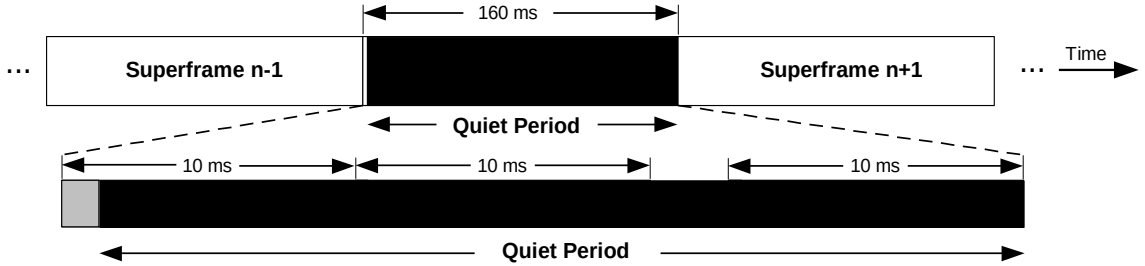
IEEE 802.22 – MAC Features

- Connection-oriented MAC, establishes connection IDs and service flows which are dynamically created
- QoS – Various types of QoS services are supported (see below). ARQ supported. Uni-cast, Multi-cast and broadcast services are supported.
- Cognitive functionality –
  - Dynamic and adaptive scheduling of quiet periods to allow the system to balance QoS requirements of users with the need to quiet down the network to support spectrum sensing. Quiet periods range from 1 symbol (approx. 1/3 ms) to one super-frame (160 ms)
  - Subscribers stations can alert the BS of the presence of incumbents in a number of ways. Dedicated - Urgent Co-existence Situation (UCS) messages or lower priority MAC messages
  - BS can ask one or more subscribers to move to another channel in a number of ways using the Frame Control Header (FCH) or dedicated MAC messages

QoS	Application
UGS	VoIP, T1 / E1
rtPS	MPEG video streaming
nrtPS	FTP
BE	E-mail
Contention	BW request etc.



Intra-frame quiet period scheduling

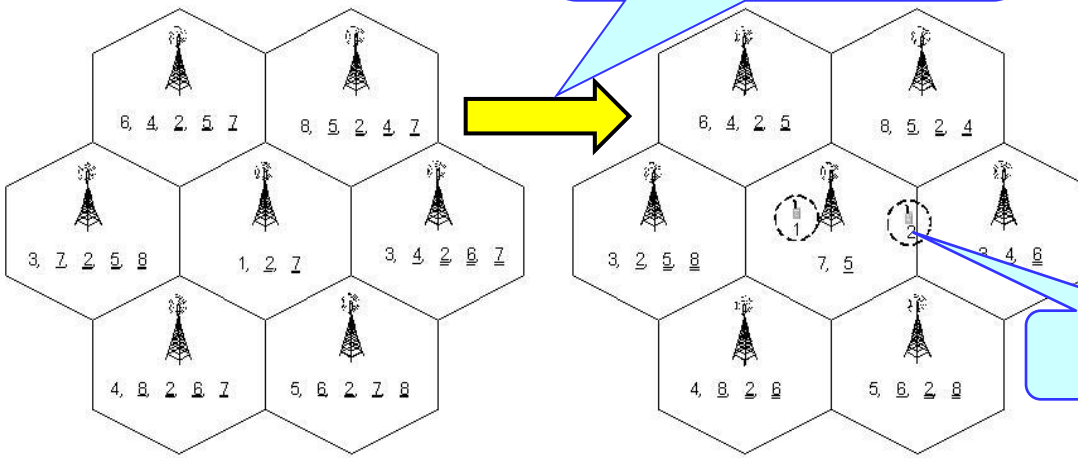


Inter frame quiet period scheduling

IEEE 802.22 – Self Co-existence

Spectrum Etiquette
(Enough channels available)

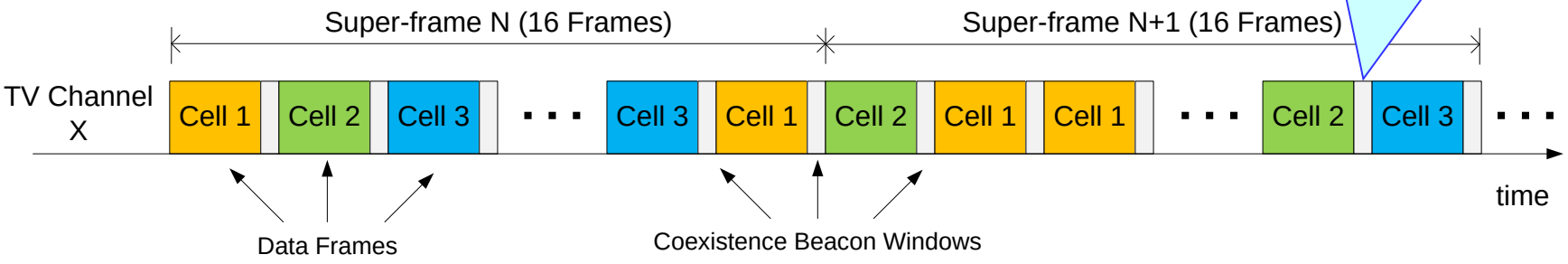
Requires that information on operating, backup and candidate channels of each cell is shared amongst WRAN cells: exchanged by CBP bursts.



Number x – represents operating channel
Number y – represents backup channel
Number z (double underline) – represents candidate channel

On Demand Frame Contention
(Two or more cells need to co-exist on the same channel)

Self-coexistence window (SCW) does not have to be allocated at each frame.



IEEE 802.22 – Additional Features

Technology	Cognitive	Will Protect Incumbents?	Optimized for VHF / UHF bands?	Provides Accurate Indoor / Outdoor Geolocation?	Database Access Method and Timers Defined?	Rural Broadband with Less Expensive Backhaul?
802.22 (WRAN)	Yes	Yes	Yes	Yes	Yes	Yes

1. **Regulatory Domain Specific Switches** – Allows 802.22 features to be switched ON or OFF based on regulatory domain specifications. E. g. Spectrum Sensing can be turned OFF in the US.

2. **Access to the Incumbent Database** – IEEE 802.22 WG has gone to great lengths to define the messaging format, techniques, and timers to access the incumbent database. We even recommend the technology for secure access to the database.

3. **Portability** - The IEEE 802.22 standard supports portable devices. Messaging has been added that sends an update to the Base Station if the device has moved by +/- xx meters based on the regulatory domain requirements. The BS then acts as a proxy and refreshes the available channel information.

4. **Ensuring that Regulatory Domain EIRP Requirements are not exceeded**: IEEE 802.22 ensures that the regulatory domain specifications for the EIRP are not exceeded.

5. **Accurate Indoor NLOS Geolocation**: Indoor NLOS geoocation has traditionally been very difficult. IEEE 802.22 provides ways to perform accurate indoor NLOS geolocation

References

- IEEE 802.22 Working Group Website – www.ieee802.org/22
- Apurva Mody, Gerald Chouinard, “Overview of the IEEE 802.22 Standard on Wireless Regional Area Networks (WRAN) and Core Technologies” http://www.ieee802.org/22/Technology/22-10-0073-03-0000-802-22-overview-and-core-technologies.pdf